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Xin Cai, Chulhong Kim, Manojit Pramanik, Lihong V. Wang, "Photoacoustic tomography of foreign bodies in soft biological tissue," Proc. SPIE 7564, Photons Plus Ultrasound: Imaging and Sensing 2010, 75643H (23 February 2010); doi: 10.1117/12.845942

SPIE.

Event: SPIE BiOS, 2010, San Francisco, California, United States

Photoacoustic Tomography of Foreign Bodies in Soft Biological Tissue

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ABSTRACT

Ultrasound imaging suffers from poor sensitivity (~50%) and specificity in detecting small foreign bodies in tissue. Hence, alternative imaging methods are needed. Photoacoustic (PA) imaging takes advantage of strong optical absorption contrast and high ultrasonic resolution. This work employed a PA imaging system to detect foreign bodies in biological tissues. To achieve deep penetration, we used near-infrared light and a 5-MHz spherically focused ultrasonic transducer. PA images were obtained from objects (glass, wood, cloth, plastic, and metal) embedded in chicken tissue. The location and size of the targets from the PA images agreed well with those of the actual samples. Objects were imaged more than 1 cm deep. Spectroscopic PA imaging was also performed on the objects. These results suggest PA imaging can potentially be a useful intraoperative imaging tool to identify foreign bodies and discriminate viable tissues in wounded patients.

Keywords: photoacoustic, foreign body, soft tissue imaging.

1. INTRODUCTION

Wounds, especially those inflicted by blast effects, weapons, or other explosions, may be dirty and contain debris from the environment. Furthermore, the wounded tissue is devitalized. Treatment is more likely to work well when foreign bodies and devitalized tissue are identified and removed early. Unfortunately, other than ultrasound imaging, current imaging modalities for foreign body detection, suffer from poor sensitivity (~50%) and specificity in detecting small foreign bodies.[1] Moreover, distinguishing vital from nonvital tissues in wounds is challenging. PA imaging, however, can image blood vessels, can provide high resolution without extrinsic contrast agents, and can image much deeper than other optical technologies. No signal averaging is performed in data acquisition, which potentially assures the real time display of the wound areas.

2. MATERIALS AND METHODS

2.1 Experimental setup[2]

A reflection mode PA imaging system[2] was used. Upon laser excitation, tissue generated ultrasonic waves, also known as photoacoustic (PA) waves. The PA waves were received by an ultrasonic transducer,

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Photons Plus Ultrasound: Imaging and Sensing 2010, edited by Alexander A. Oraevsky, Lihong V. Wang,
Proc. of SPIE Vol. 7564, 75643H · © 2010 SPIE · CCC code: 1605-7422/10/$18 · doi: 10.1117/12.845942

amplified by an amplifier (5072PR, Panametrics-NDT), digitized by an oscilloscope (Tektronix TDS 5054), and stored in a computer, which also controlled the XY-linear translation stage (XY-6060, Danaher Motion, Washington, D. C.) for raster scanning. A photodiode (DET110, Thorlabs) was used to compensate for the instability of laser pulses.

To achieve deep penetration of light, a tunable near-infrared Ti:sapphire laser (LT-2211A, LOTIS TII) pumped by a Q-switched Nd:YAG laser (LS-2137/2, LOTIS TII) was used for PA excitation. The laser pulse duration was less than 15 ns and the repetition rate was 10 Hz. The laser beam incident on the tissue surface was controlled to be less than the ANSI standard for maximum permissible exposure (31 mJ/cm^2).[3]

To receive deep PA signals with minimal ultrasonic attenuation, a 5 MHz central frequency ultrasonic transducer (V308, Panametrics-NDT, Watham, Maryland) was used. This transducer has a spherical focus with a 2.54 cm focal length, a 1.91 cm diameter active element, and a 72% nominal bandwidth based on full width at half maximum (FWHM) amplitudes. The spatial resolutions were 144 μm in the axial direction and 560 μm in the transverse direction. The scanning time depended on the laser pulse repetition rate (PRR), the scanning step size, and the field of view (FOV). Typical values for a 1-D scan are scanning step size = 0.1 mm and a laser PRR = 10 Hz. The acquisition time = ~25 sec for a B-scan. Note that no signal averaging was done for any of the images. The transducer was located inside a water container with an opening of 5 cm x 5 cm at the bottom, sealed with a thin, clear membrane. The object was placed in close contact under the membrane, and ultrasonic gel was used for coupling the sound.

To reducing surface PA wave generation, a concave lens, a spherical conical lens, and an optical condenser were used to form the dark-field illumination.

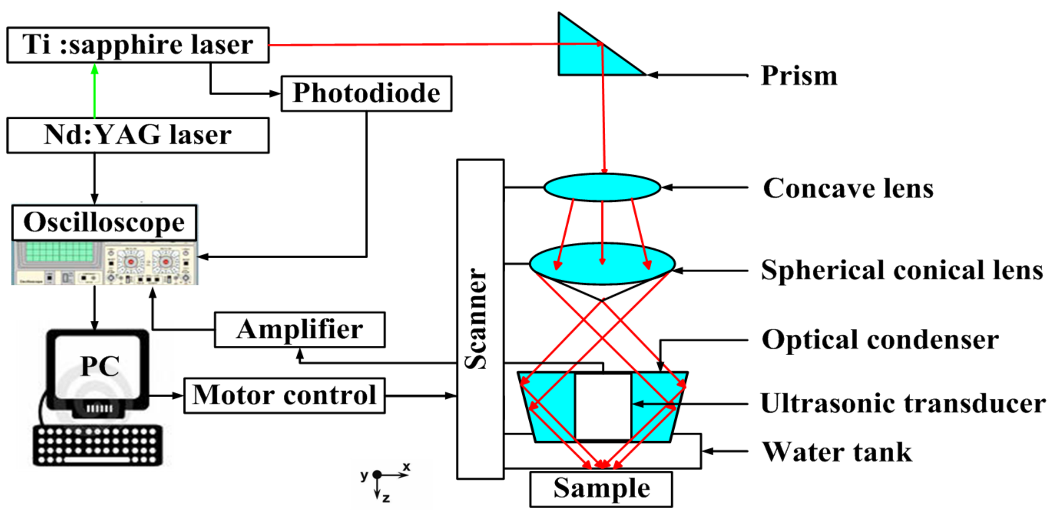

Fig. 1. Schematic of the deep reflection-mode photoacoustic imaging system.

2.2 Preparation of the foreign body samples

Chicken breast tissue was the background medium mimicking human breast tissue.[5] Pieces of randomly chosen foreign bodies with arbitrary shapes, comprising an iron blade, two pieces of plastic, two pieces of wood, two pieces of cloth, and a piece of glass, were embedded into the chicken breast tissue at depths ranging from 3 mm to 10 mm.

3. RESULTS

We obtained PA images with accurate contrast of various foreign bodies embedded in chicken tissues. Figure 2 shows PA B-scan images at an optical wavelength of 766nm. Most objects are clearly seen in the PA images. Two exceptions are a piece of transparent plastic and a piece of wooden stick, both of which those have low optical absorption coefficients at the excitation wavelength.

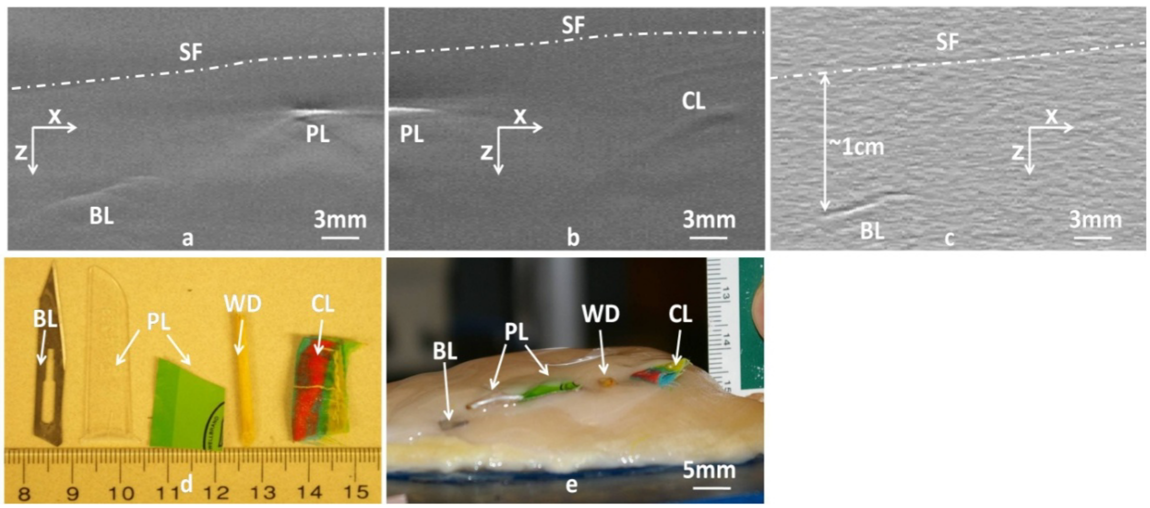

Fig. 2. PA B-scan images and digital photographs. (a),(b),(c) PA B-scan images. Objects were embedded in chicken breast tissue. (d), (e) Digital photographs. SF: signals from tissue surface; BL: blade; PL: plastic; WD: wood; CL: cloth. There are no signals from the transparent plastic and the wood stick.

Figure 3 shows PA maximum amplitude projection (MAP) images of various foreign bodies. The shapes of the objects agree well with those of the actual samples.

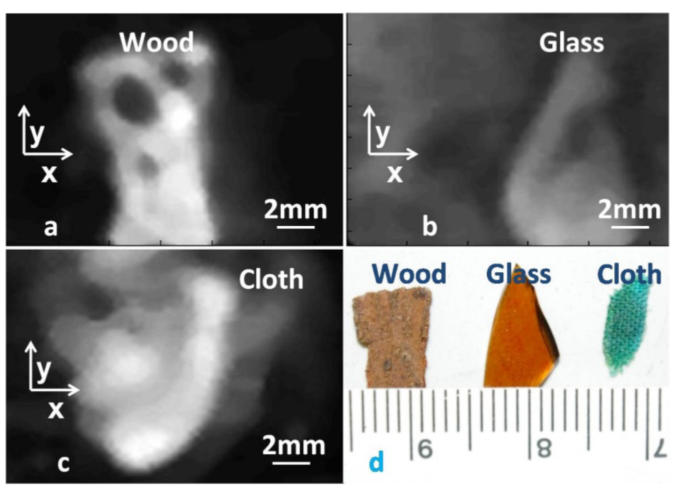

Fig. 3. PA maximum amplitude projection (MAP) images and digital photographs. (a),(b),(c) PA MAP images. Objects were embedded in chicken breast tissue. (d) Digital photograph of the objects embedded inside the chicken breast tissue.

4. CONCLUSIONS AND DISCUSSION

We have demonstrated that photoacoustic imaging can be used as an imaging tool to detect foreign bodies in biological tissue. Other current imaging modalities for this purpose have advantages and disadvantages. Ultrasound imaging is widely used in clinics because of its real-time display, zero radiation exposure, and affordable price. However, it has poor sensitivity and low contrast, making it hard to detect small foreign bodies. Photoacoustic imaging is sensitive to strong intrinsic and extrinsic optical contrasts. In addition, it is cheap and portable, comparable to conventional ultrasound imaging systems. Therefore, photoacoustic imaging can be extremely useful during the intraoperative process. Simultaneous PA images and pure ultrasound images from the same cross-sections of the sample can be obtained.[6] Therefore, the combination of photoacoustic imaging and ultrasound imaging can significantly increase the sensitivity and specificity of detecting foreign bodies.

5. ACKNOWLEDGMENTS

This work was sponsored by National Institutes of Health grants No. R01 EB000712, No. R01 NS46214 (Bioengineering Research Partnerships), No. R01 EB008085, and No. U54 CA136398 (Network for Translational Research). LVW has a financial interest in Microphotoacoustics, Inc. and Endra, Inc., which, however, did not support this work.

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